# Smart Sensor for Extended Range Optical Imaging

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## LONG TERM OBJECTIVE

The long term goal of this program is to develop a next generation of underwater optical imaging systems that utilize new sensors and advanced signal processing in order to acquire more information about the ocean environment.

## SCIENTIFIC/TECHNICAL OBJECTIVES

The specific goal of this project is to demonstrate the utility of a fast read out 1 dimensional CCD camera in concert with a scanning laser system. Theoretically, the system should permit the observation of microscale bathymetry (1 mm - 10 cm) at ranges of 2 m to 10 m with concurrent observation of bottom albedo at extended imaging ranges (3-7 total attenuation lengths). The system is called L-Bath for laser bathymetry.

## APPROACH

The approach taken here is to use a narrow illumination source with a narrow angle receiver in order to reduce common volume backscatter between source and receiver. In addition, the position at which the narrow angle source is incident upon the sea floor is measured with a CCD array. As such, the design offers the simultaneous acquisition of both reflectance and bathymetric maps of underwater targets with higher contrast and resolution than traditional systems, by minimizing backscatter produced in illumination and actively eliminating forward scatter reflected from the target. The system reduces backscatter by illuminating the target scene element by element using a highly collimated pulsed laser beam of minimal cross-section and angular divergence. The laser scans the sea floor in linear fashion perpendicular to direction of motion and builds an image line by line as it moves through the water. Each laser pulse arriving at a new position on the target is synchronously imaged by a high speed linear CCD camera positioned a short distance from the scanner. Each line scan captures the position of the target spot and the imaged transect provides an energy distribution map of the target spot and its surroundings. The center of the target spot is identified as the detector pixel with maximum response, and by selective extraction of a single pixel value and its position from each record, provides a means whereby pixels with weaker response resulting from scattered light contributions are excluded, thus eliminating forward scatter. Bathymetric information for each scanned element of the target is determined by triangulation between the scanner, target spot and camera. The combined reduction in both back- and forward scattering, and the use of a high resolution solid state camera sensor provides high contrast images with accurate depth resolution on the order of centimeters at 10 m range. The simultaneous production of both reflectance and bathymetric images from the same data acquisition demonstrates synergistic value in underwater object identification.

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**TASKS COMPLETED**

Development of the system has centered on several areas (1) A theoretical exploration of the potential performance of such a system and the influence that various system components have on that performance; (2) the construction of the system; (3) the deployment of the system under a range of laboratory conditions and at sea (4) the development of image and signal processing techniques for extraction of important information from the data and, (5) the analysis of data produced by the system using the signal processing techniques developed in (4) on the data collected in (3) in order to reconcile the results with the theoretical predictions.

**RESULTS**

*Theoretical Exploration of the system Performance*: The system performance was examined from a number of different viewpoints. From the viewpoint of the system geometry, the accuracy of bathymetric data is fundamentally a function of the accuracy at which the laser angle of the projected beam can be measured in concert with the location of the beam on the CCD array in consideration of the separation between the camera and the lights. Extensive experiments were performed in the lab in order to verify that the system components could be compatible with our intended specifications. In order to accomplish the goals of the system, custom waveforms were invented to drive the mirror assembly so as not to excite nonlinear oscillations in the system response which would prevent the system from being operated in a reliable and reproducible manner. From the viewpoint of the system radiometry, the photon budget of the system was developed and used to predict the maximum number of attenuation lengths that the system would be able to operate at, under the assumption that all of the light could be imaged by a single element of the CCD chip. This number turned out to be 4 total attenuation lengths, limited only by the detector noise in this situation.

*System Construction, Instrument Description*: The underwater instrument consists of three housings; scanner housing, camera housing, and a main housing that encapsulates the main computer, auxiliary electronics and a sensor package These housings are mounted on an aluminum frame and attached to the underside of a hydrodynamical wing when towed in water. Both the scanner and camera are mounted on a common chassis so that their respective one-dimensional fields-of-view lie within the same plane. The camera-scanner separation and mounting angles can be modified, if required, to obtain optimal scene coverage for a particular depth. Both the scanner and camera are connected to the main housing by flexible high pressure conduits. The main housing contains the drive and acquisition electronics for the scanner and camera, including a computer with acquisition and control boards, sensor package and power supplies. The sensor package includes a compass, high precision dual axis tilt sensor, and pressure transducer to measure depth below surface.

As a towed instrument a 200 m electro-optical tow cable pulls the system through the water while delivering power, laser light and communication link between the surface and the submerged instrument. At the surface, light output from a Spectra-Physics solid state Nd:YAG laser is coupled into a high power optical fiber and delivered to the scanner housing. Power is supplied by electrical wire, and the data link by two 50/125 m communication optical fibers. A third communication fiber is used to send video images from an auxiliary CCTV camera, positioned nadir-viewing in the main housing. The system can also be deployed in a semiautonomous mode from an AUV with propulsion and power from the AUV.

As the system moves through the water a series of laser pulses are deflected by a scanning mirror onto the sea floor in a linear fashion during a single bathymetric sweep of the sea floor. By synchronization, the position of each pulse on the sea floor is captured by a line scan CCD camera and the angle of the deflected laser pulse determined by simultaneously reading the scanner encoder voltage. Information from the sensor package is simultaneously read to correct for depth and angular attitude variations of the system during field operation. By triangulation, the depth of each laser target spot imaged by the camera can be determined and corrected by sensor package data.

*System Deployment*: In order to test the system performance, several lab tests and also at-sea cruises were accomplished. Lab tests consisted of deploying the system in several salt water tanks located at SIO. In one case, the system was used to image objects which were 1.6 m away (Dec, 1996). In a later test, the system was used to image objects which were 3.6 meters away (May, 1997). In addition, several cruises were undertaken to evaluate the performance of the system at sea. In an early sea trial (June, 1996) the system telemetry system was tested complete with a sensor package for monitoring the tow body stability of the system. In a more recent sea test, July, 1998, the system was deployed over a three day period in order to judge the performance of the system. In one case a calibrated range target was suspended from the frame. All tests were successful in that several high quality sets of data were obtained which were then processed to examine the systems performance in terms of bathymetric resolution.

*Development of Image and Signal Processing Techniques*: Since the bulk of our efforts have been mainly dedicated to the creation of the system and insuring that it has performed, from a hardware point of view, up to specifications, the development of image and signal processing techniques has been kept simple, however, we have been surprised at the impact that some of these ideas have had on the images that we have processed. Here, a qualitative description of the methods is presented. Since the system produces a set of line data for each position of the laser beam, each scanned line consists of an image of the beam as it sweeps over the field of view of the CCD camera for each laser position. This creates an image of 1024 (laser positions) by 1024 (camera elements) for each line scan. Thus, each line scan creates an image. Although many options seem available for processing the data, to start with, two images are created, one of the target reflectivity, or albedo, and the other of the target range, or depth. Under the assumption that the output beam of the laser is extremely narrow and that the bottom reflectance does not change by a large amount over very small distances, the brightest pixel in the field of view of the camera will correspond to the point at which the beam struck the bottom. This assumption also requires that the amount of backscatter created by the laser beam be small, in comparison to the value obtained from the bottom reflectivity. (Future versions of the software will relax this requirement to permit operation in more turbid environments). As such, the location of the brightest pixel is assumed to be related to the angle at which the camera is sensing the bottom, relative to the distance between the source and the receiver and the range of the object at that position is computed. In addition, the reflectivity of the bottom at the brightest pixel is used to create a map of bottom reflectance, relative to the projection angle of the laser beam. Using these simple methods, we have obtained remarkably good images of both image reflectance (even with a moderately wide illuminator) and also the bottom range.

*Experimental Results*: The first bathymetric images were obtained in a salt water test tank. With its tow wing removed, the L-Bath system was suspended and lowered into the tank so that both the scanner and camera housings were submerged. At the bottom of the tank approximately 1.6 m distance away, a relief target consisting of a cinder block, adjustable wrench and pyramid shaped cement block were place in view of the system. In this test, each laser scan of the target comprised of 1024 line scan acquisitions - with each pixel providing a spatial resolution of approximately 1 mm. To build an image complementing this resolution, L-Bath was manually advanced in 1/20 inch (1.27 mm) steps after each laser sweep until the complete target scene had been scanned (~400 steps). The clarity of the sea water and short distance between L-Bath and facilitated identification of the pixel position of the target which was determined as the maximum pixel in each line scan. Bathymetric and reflectance results, derived from the data were calculated using equations developed in [K. D. Moore et. al]. To yield bathymetric data the system was carefully calibrated so that various parameters including the angular offset between the scanning beam and the receiving aperture as well as various

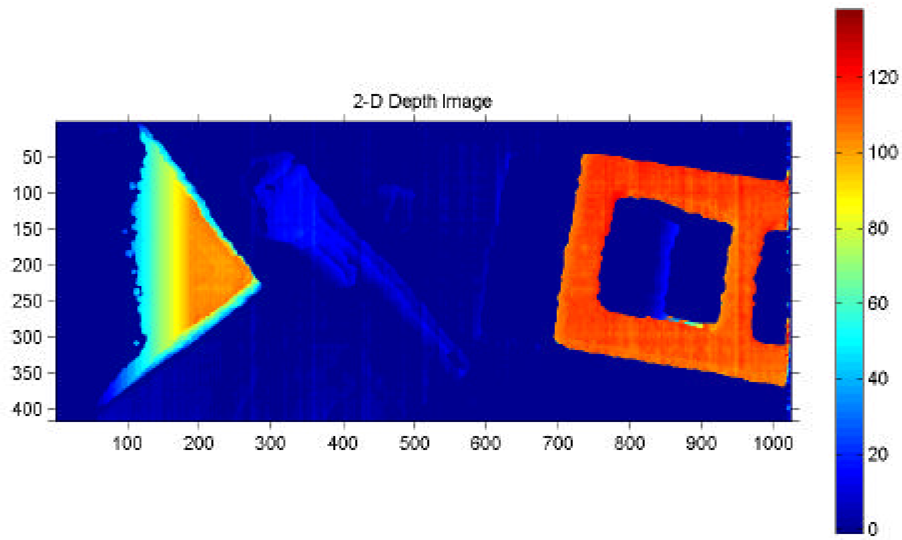


***Figure 1: A range image of the pyramid, wrench and cinder block. Units are in mm of height, relative to the mounting plane of the objects.***

instrument values such as the laser beam angle when a zero voltage signal was applied to the scanner were determined by noting the resulting pixel position of the target spot when a flat target was scanned at a similar range of 1.6 m in water. Figure 1 shows a depth image which was obtained in computing the range of the targets from the system. Note that the color map used to display the image does not depict target reflectivity but rather distance. In addition, figure 2 shows a zoom of the wrench from a Figure 1, illustrating the superior imaging capability of the system. Finally, both albedo and range were combined to produce Figure 3, a 3-dimensional image of height which was overlaid with reflectivity. As a final test of the system's performance in a sea-going environment, we attached a calibrated test target with precision steps milled into it to quantify the systems range capability. Results of the test indicated that by averaging several hundred scans (obtained at 10 Hz) that we could judge the resolution of the test target range to a distance of 1.5 mm at a range of 2 m.

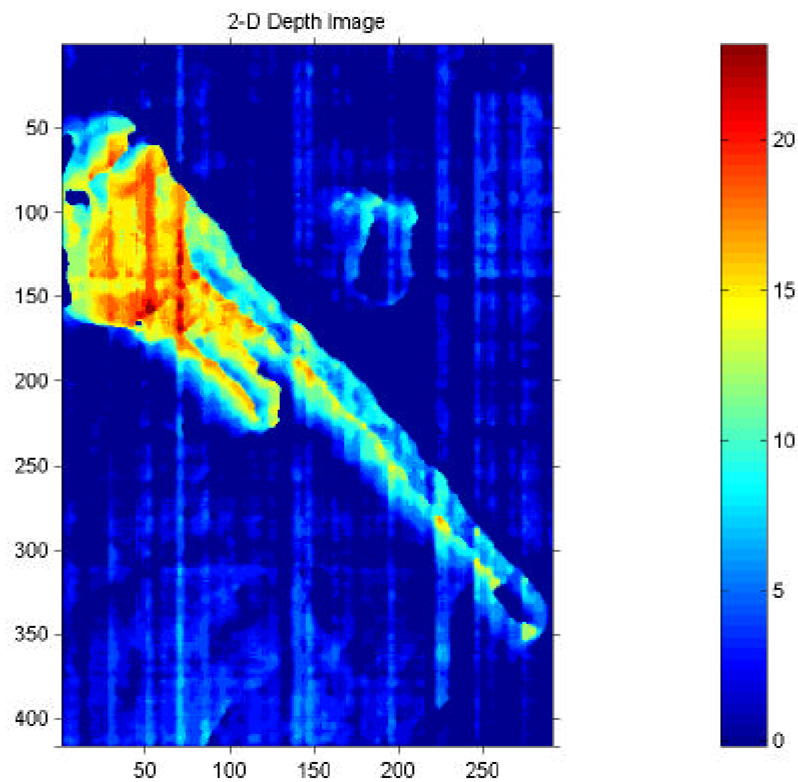


***Figure 2: A magnification of the wrench and shackle (approximate units are mm)***

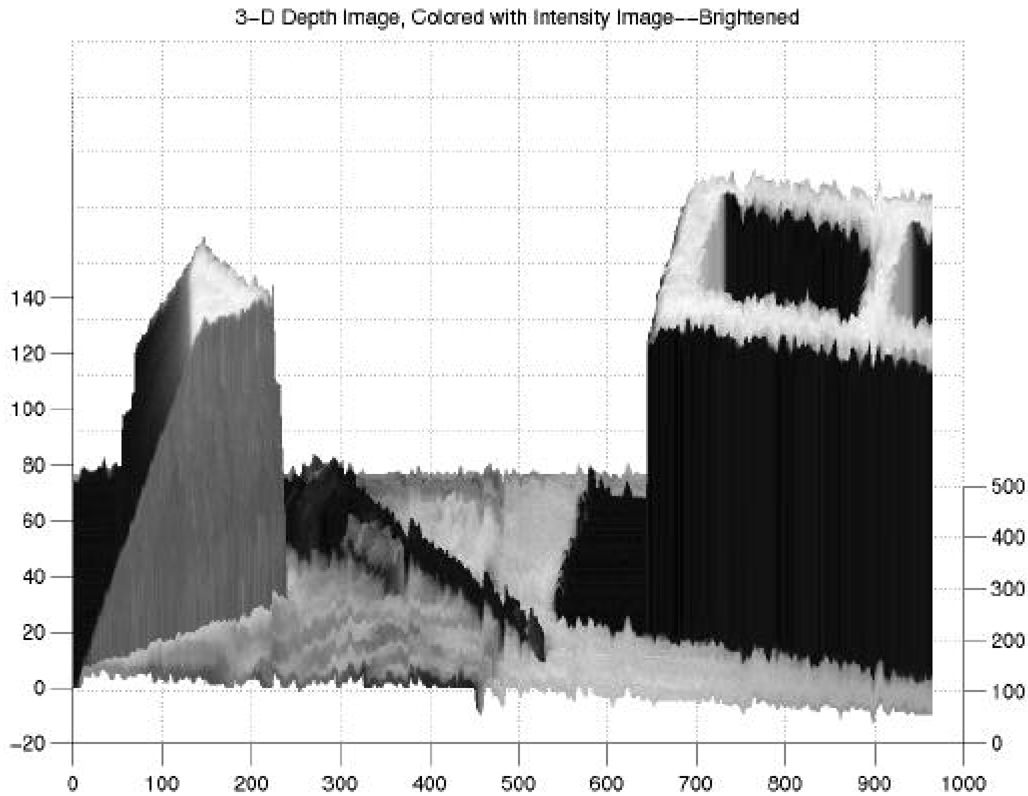


***Figure 3: The Microbathymetry map from the range image with the albedo overlaid.***

## IMPACT

We believe that the evolution of this instrument will have important ramifications for looking at objects that are lying on the sea floor which have some surface expression.  Hopefully, the important advantage of our device will be the ability to distinguish, at extended ranges, between man made and natural objects.

## TRANSITIONS

Several other programs within the NAVY have expressed interest in our device.  Based on our at-sea data using a calibrated test target, a new ONR DRI in high frequency backscatter has decided to fund our participation.  We will be measuring bottom microbathymetry at the same time that the acoustics experimentalists are measuring bottom backscatter.  In addition, other parts of the NAVY have expressed interest in testing our system for various purposes in order to obtain quantitative bottom images of articles on the sea floor.

## RELATIONSHIPS TO OTHER PROJECTS

As stated above, the device is going to be used to measure bottom microbathymetry in a new ONR DRI which will measure bottom backscatter. We have also been pursuing the possibility of using the system to help marine archaeologists to obtain quantitative 3-dimensional bottom images of shipwrecks. L-Bath also measures a line through the water radiance pattern. This provides many interesting opportunities for performing pelagic studies with the system to study particulate matter in the water column, fluorescence of small particles, as well as measurement of the volume scattering function at the angles that the system is interrogating. In conclusion, we expect this tool to become a part of many studies that we are planning.

## REFERENCES

K.D. Moore, J.S. Jaffe and B. L. Ochoa. Development of a new underwater bathymetric laser imaging system: L-Bath. J. Atmos. and Oceanic Tech., 40 ms. pgs. (1998). (SUBMITTED - August, 1998)

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